

Market Perspective Trends and Timing

Transformations in Lighting
2008 DOE Solid-State Lighting R&D Workshop

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Outline

- ❑ Introduction
- ❑ Markets
- ❑ Lighting
- ❑ Outlook

HB LED Market Analysis

- ❑ Market is worldwide in scope
 - Main production and consumption are in US, Europe, Japan, Taiwan, S. Korea, China, SE Asia
 - ❑ Market analyzed in terms of packaged devices (lamps, SMDs, multichip, high-power packages)
 - ❑ Materials include InGaAlP (red-orange-yellow) and InGaN (blue, blue-green, green, white)
 - Higher performance, “qualified” devices
 - ❑ Market segmented and sub-segmented by applications that have similar functionality
-

HB LED Application Segments

Illumination



Signals



Other
Indicators, small displays
amusement, misc. other

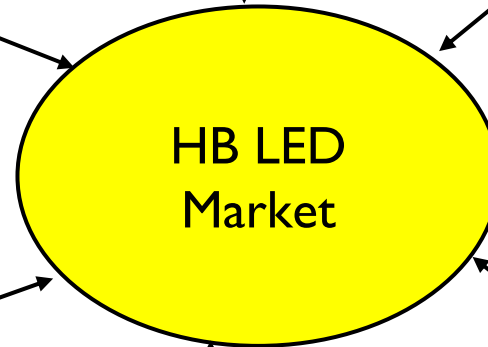
Mobile Appliances



Signs and Displays



Automotive



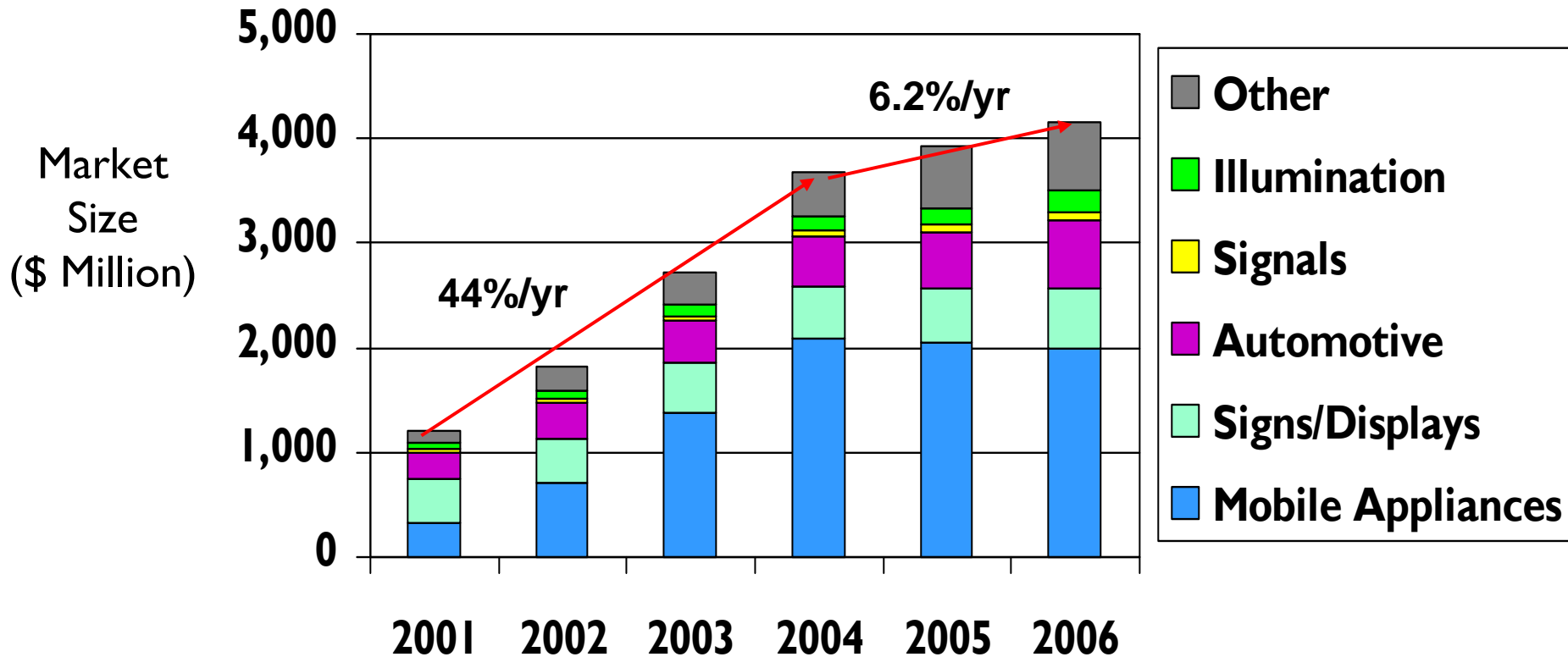
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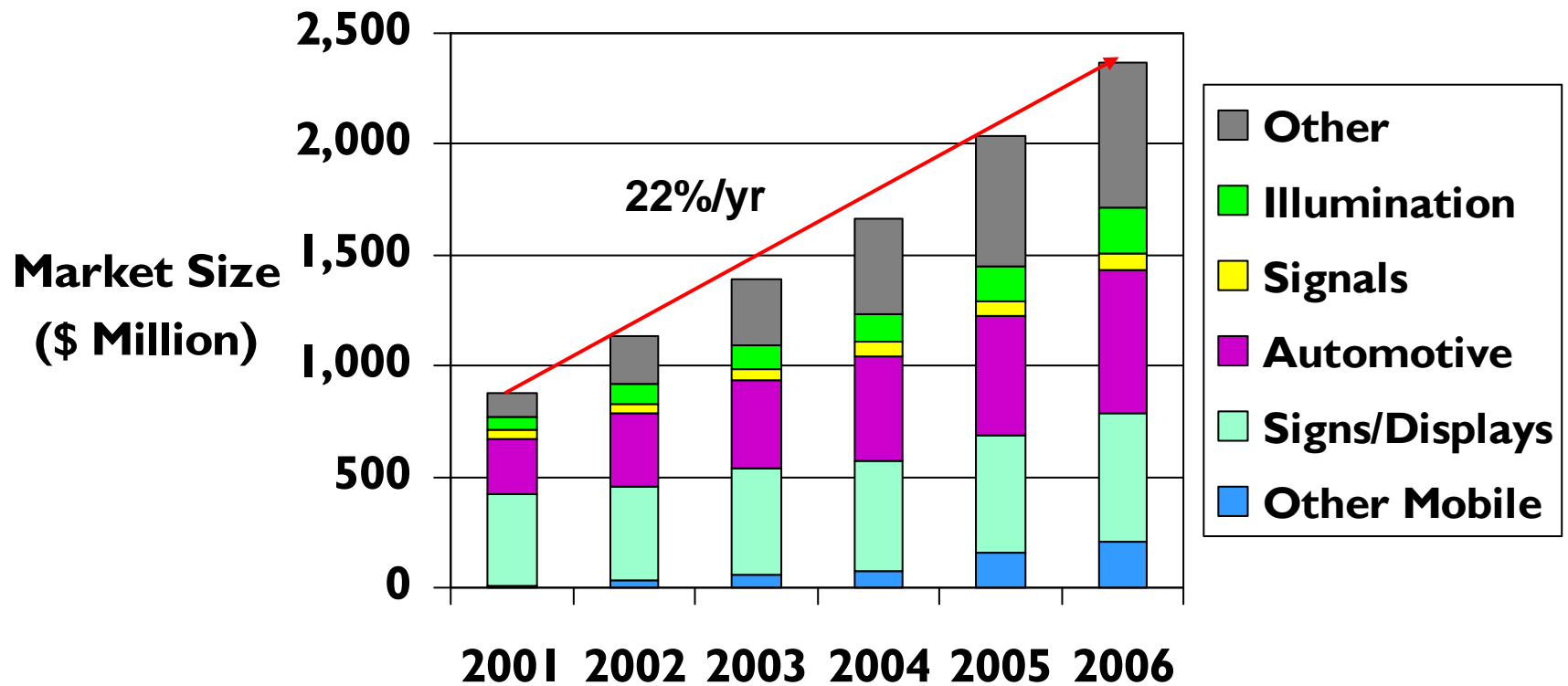
HB LED Market Trends

- ❑ Market continued its “slow growth” phase in 2006 – similar patterns to 2005
- ❑ Overall market growth was 6% to \$4.2 billion
- ❑ Heavily influenced by ongoing decline in mobile phone market
- ❑ Other applications continued to have attractive growth rates
- ❑ Substantial ASP erosion across many product types

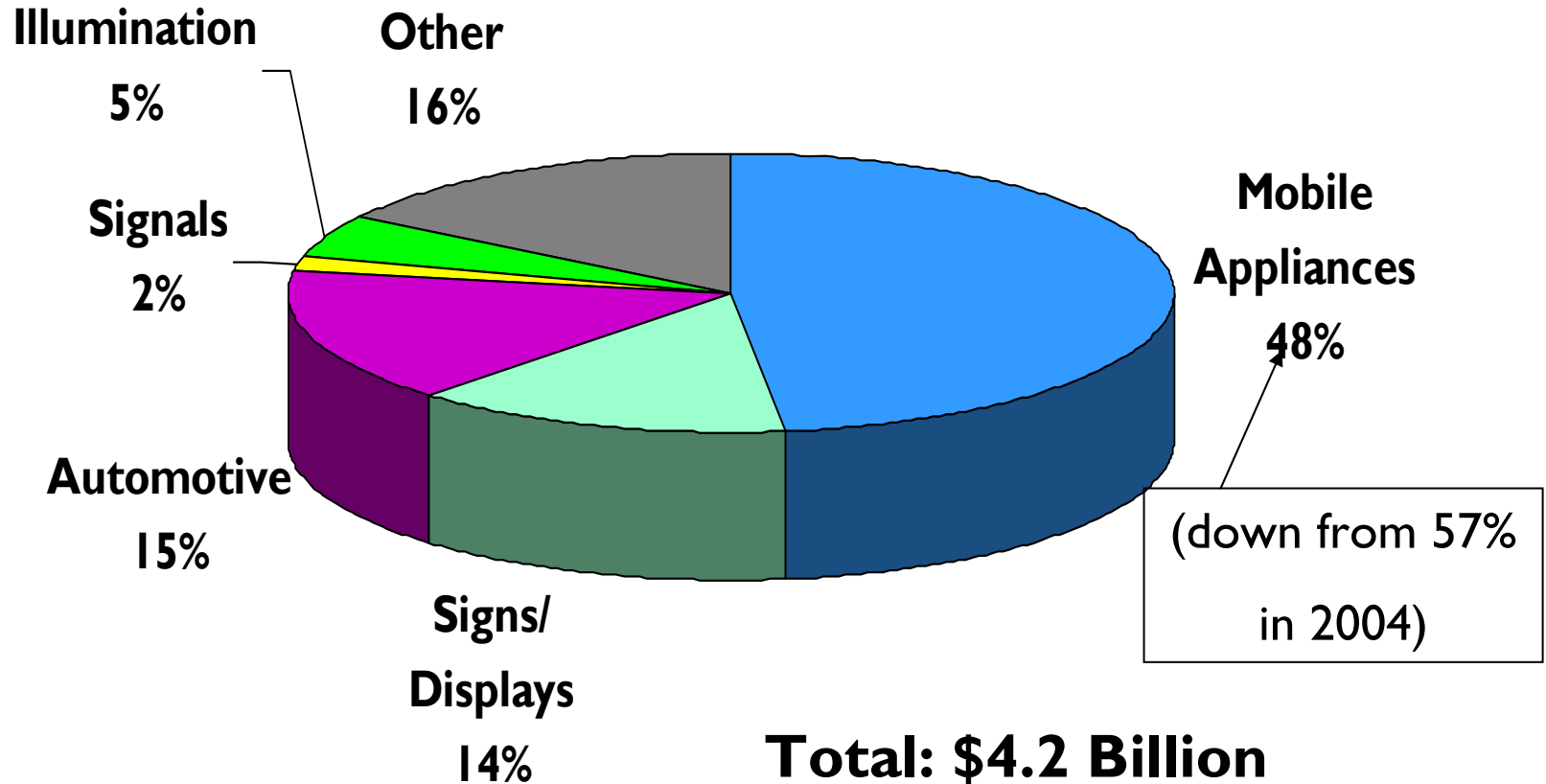
Recent Market History



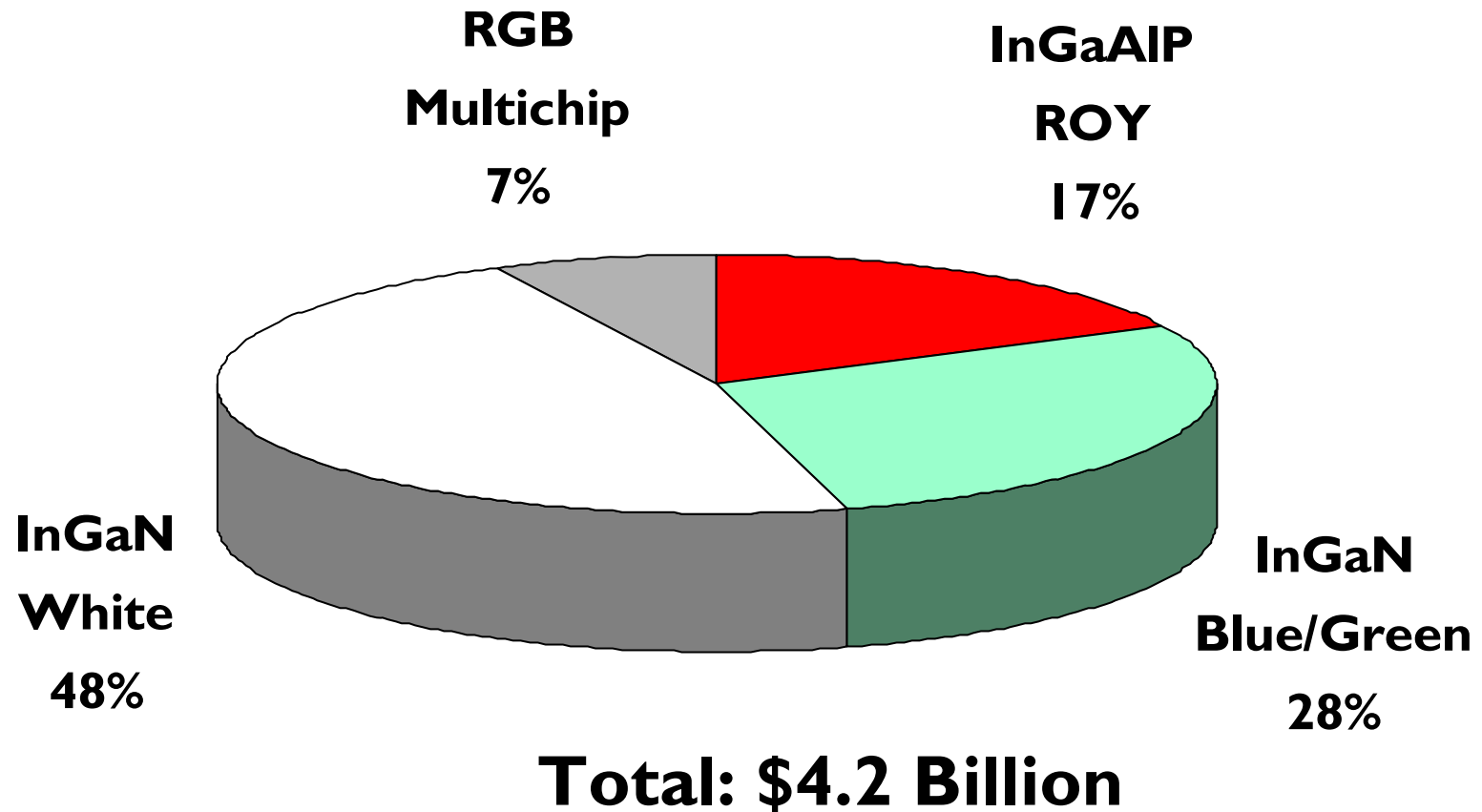
Market Growth Without Mobile Phones



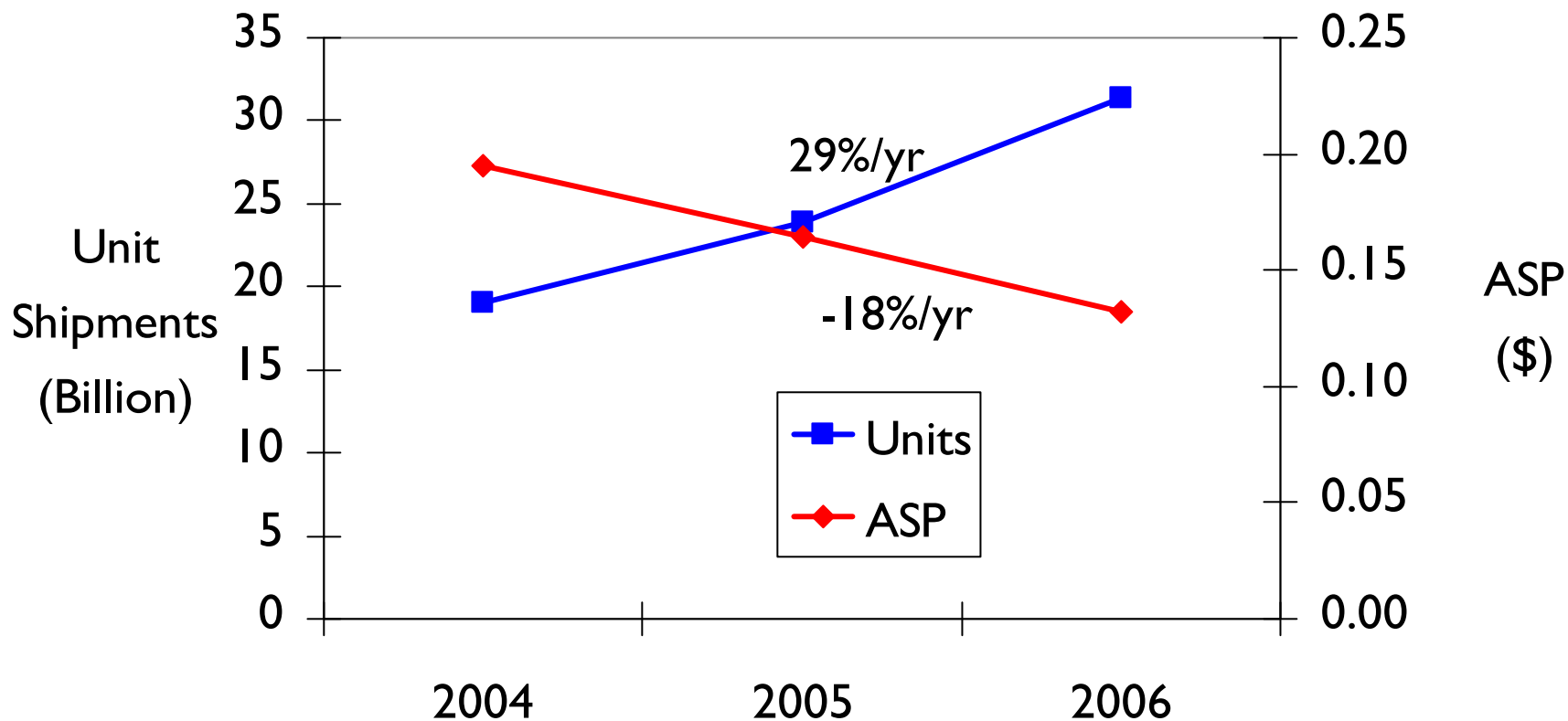
2006 Market by Application



2006 Market by Color



HB LED Units and ASPs



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Lighting-

10 Significant Near-Medium Term Applications

- ☐ Architectural
- ☐ Channel letter/
contour lighting
- ☐ Consumer portable
(e.g. flashlights)
- ☐ Residential
- ☐ Machine vision
- ☐ Retail display
- ☐ Entertainment
- ☐ Safety/Security
- ☐ Outdoor area
- ☐ Off-grid (generally
solar-powered)

Market for HB LEDs in Lighting

- ❑ The 2006 market for HB LEDs used in lighting was \$205 million
- ❑ Growing at around 37% per year – the highest of any HB LED application
- ❑ Projected to reach ~\$1 billion in 2011
- ❑ Majority of applications use RGB today, but white will increase to more than 60% of the market by 2011

SSL Market Drivers

- ❑ Visual appeal

- Saturated colors, near point source of light, design flexibility

- ❑ Long lifetime

- Applications with high maintenance costs

- ❑ Compact form factor

- ❑ Lack of radiated heat

- ❑ Low-voltage operation

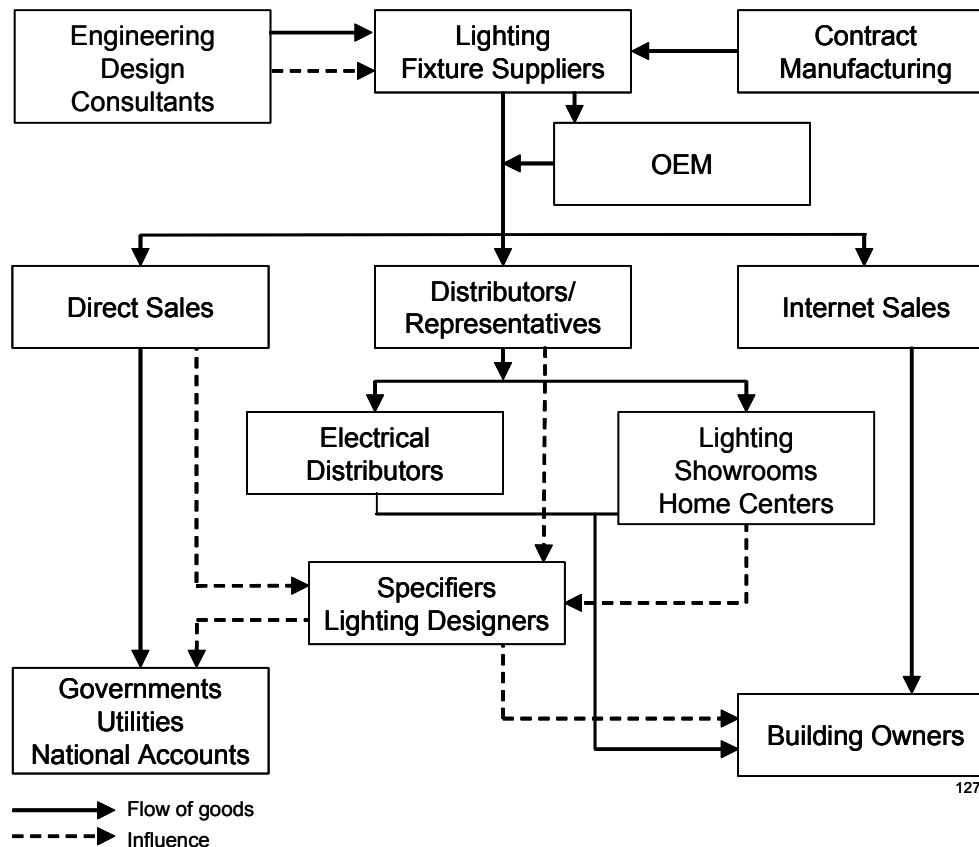
- ❑ Energy efficiency

- Colors, low wattage applications (e.g. battery and solar powered), low temperature operation

Solid-State Lighting Market

- ❑ The market is highly fragmented, encompassing many niche applications
 - Architectural lighting is the largest
 - Most applications are for colored (R,G,B) light
 - General illumination applications are starting to emerge
- ❑ Hundreds of companies worldwide are participating at the luminaire or fixture level
 - Strategies Unlimited has identified and described approximately 300 such companies, but there are more
 - Participants range from start-ups to the world's largest lighting companies

Structure of the Lighting Fixture Industry



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Status of SSL Fixture Industry

- ❑ Many small companies dedicated to SSL; high level of LED expertise
- ❑ Many large and medium lighting companies, with some interest in SSL, offer a few products
 - Most lack in-house LED expertise
 - Rely on outside consultants for design, prototyping
- ❑ Volumes are small and costs are high, independent of high cost of LEDs
- ❑ Products in the market are highly variable in terms of quality

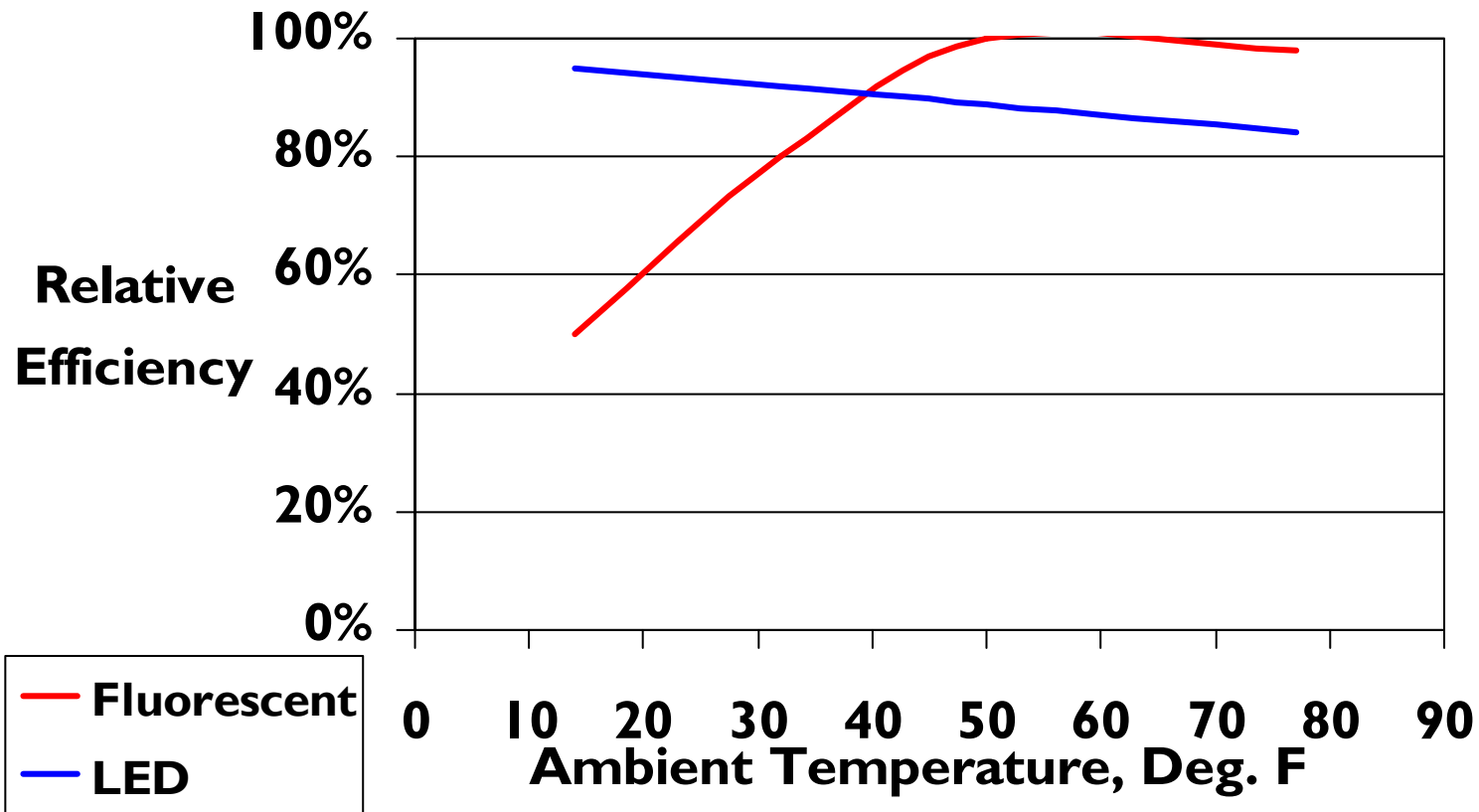
SSL Market Development

- ❑ Most product and market development is being carried out by small, specialized companies
 - With a few exceptions, e.g. Philips Lighting, Zumtobel
 - ❑ Generally, large lighting fixture company interest ranges from zero to modest (but interest is growing)
 - In-house LED expertise is minimal
 - European companies moving faster than US
 - ❑ Large companies control the access to sales and distribution channels and customers
-

Refrigerated Display Case Success Story

- ❑ Wal-Mart adoption of LED refrigerated display case lighting from GELcore was the SSL “story of the year”
- ❑ Installing in all new Sam’s Club and SuperStores from Dec. 2006, approximately 175 new stores in 2007 in US
 - Part of the Wal-Mart’s “green” strategy
- ❑ Drivers are energy and maintenance savings
 - Can use occupancy sensors to turn off lighting during low traffic periods (impossible with fluorescent due to slow start-up)
- ❑ Other supermarket chains are likely to follow Wal-Mart’s lead

Linear Fluorescent vs. White LED Relative Efficiency



Retail Display Lighting

- ❑ White LEDs are being used to provide attributes that are advantageous for certain types of products:
 - High-end retail (e.g. designer label branded stores)
 - ❑ “High-tech” look; interesting effects; design flexibility
 - Cosmetics
 - ❑ Lack of radiated heat from source
 - Jewelry
 - ❑ Sparkling appearance from point light source; compact; long life
 - Refrigerated display cases
 - ❑ More efficient than linear fluorescents at low temperatures; rapid start-up; long lifetime

Retail Display Lighting Examples



Source: Hera GmbH



Source: Nualight

Source: MAG-LED

LED lighting fixtures – a wide variety in the market

LED Lighting Fixtures (I)



Source: Altman



Source: Lighting Services Inc./
TIR Systems (now Philips)

LED Lighting Fixtures (2)



Source: ERCO



Source: Hera GmbH

LED Lighting Fixtures (3)



Source: Lucesco



Source: Herman Miller/Fuseproject

LED Lighting Fixtures (4)

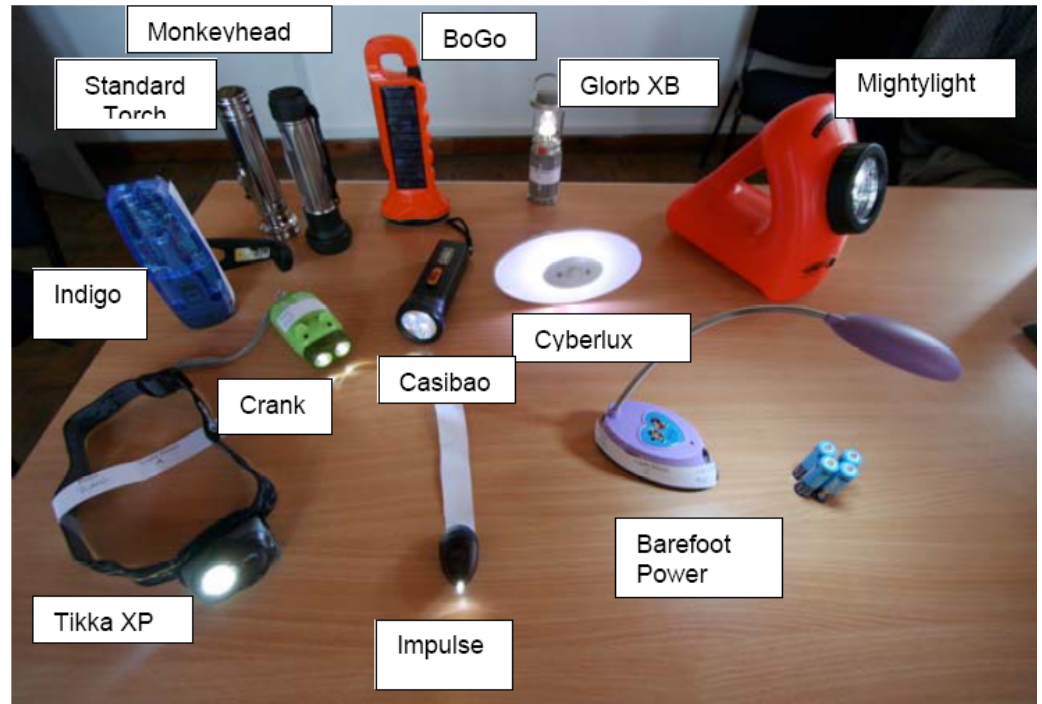


Source: Elletrica Rotaliana srl



Source: Progress Lighting

LED Lighting Fixtures (5)



Source: beta LED

LED lanterns presented to the focus group and interview participants for evaluation for the Lumina Project

LED Lighting Fixtures (6)

Solar Powered



Source: Bronzlite



Source: Advanced LEDs

LED Lighting Fixtures (7)



**Philips Solid
State Lighting--
Color Kinetics**



GE Luminations' Channel Letters



**Source:
Philips Lighting**

Opportunities for SSL

- ❑ Offer a unique lighting solution
- ❑ Create an aesthetically pleasing lighting environment
- ❑ Deliver value (on a cost-of-ownership basis)
- ❑ Provide lighting products adapted to unique physical environments
- ❑ Save energy; comply with regulatory requirements (e.g. Title 24 in California)

Challenges for SSL

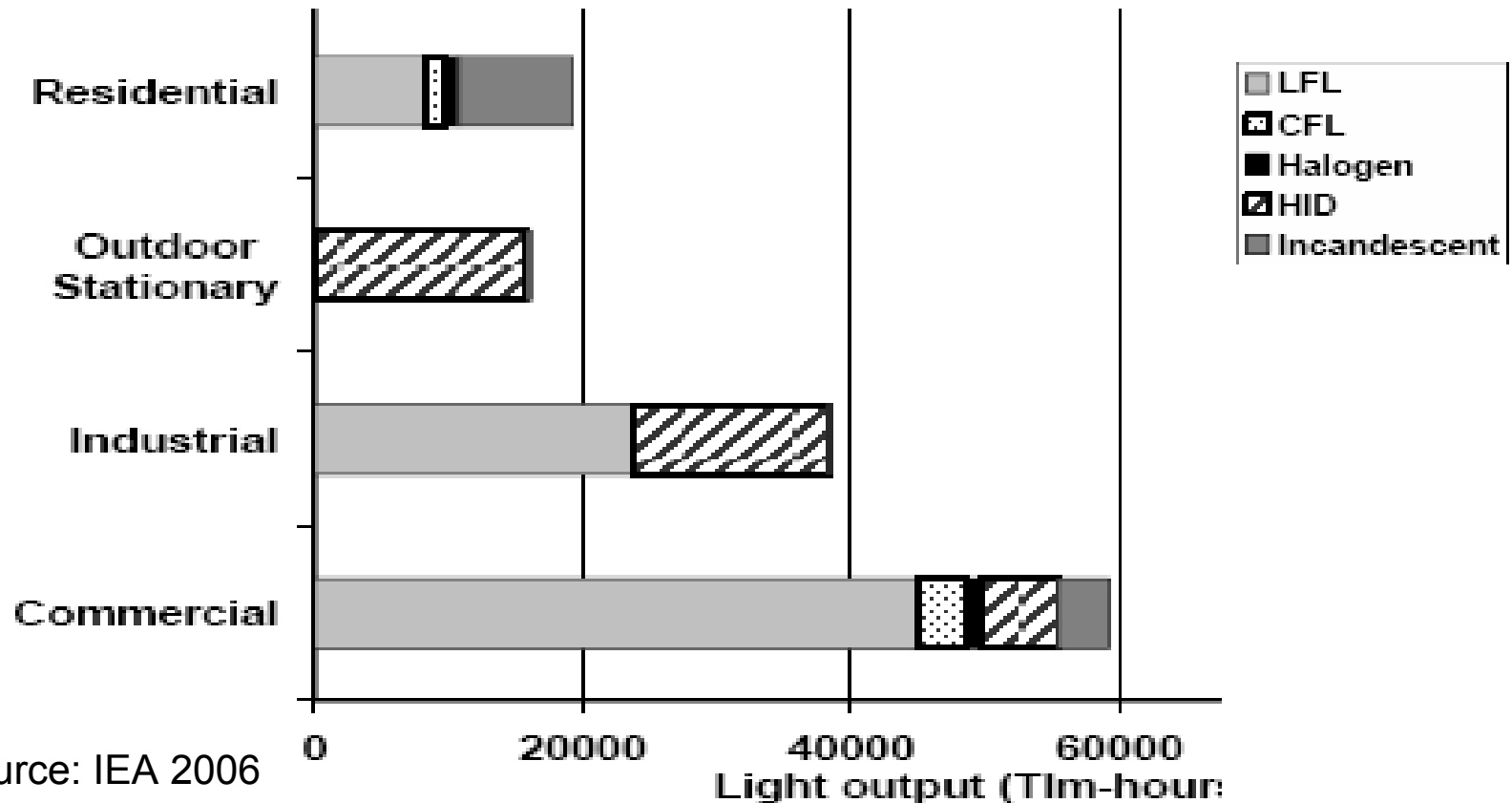
- ❑ High initial cost
- ❑ Other alternatives for energy efficiency
- ❑ Consistency of color/binning issues
- ❑ Need to provide a complete lighting solution with ease of installation
- ❑ Adapt to standard electrical interfaces and controls
- ❑ Realistic claims of performance
- ❑ Development of standards
- ❑ Need widespread base of lighting fixture designers and engineers who understand LEDs
- ❑ Need for high-efficiency light engine/fixture design

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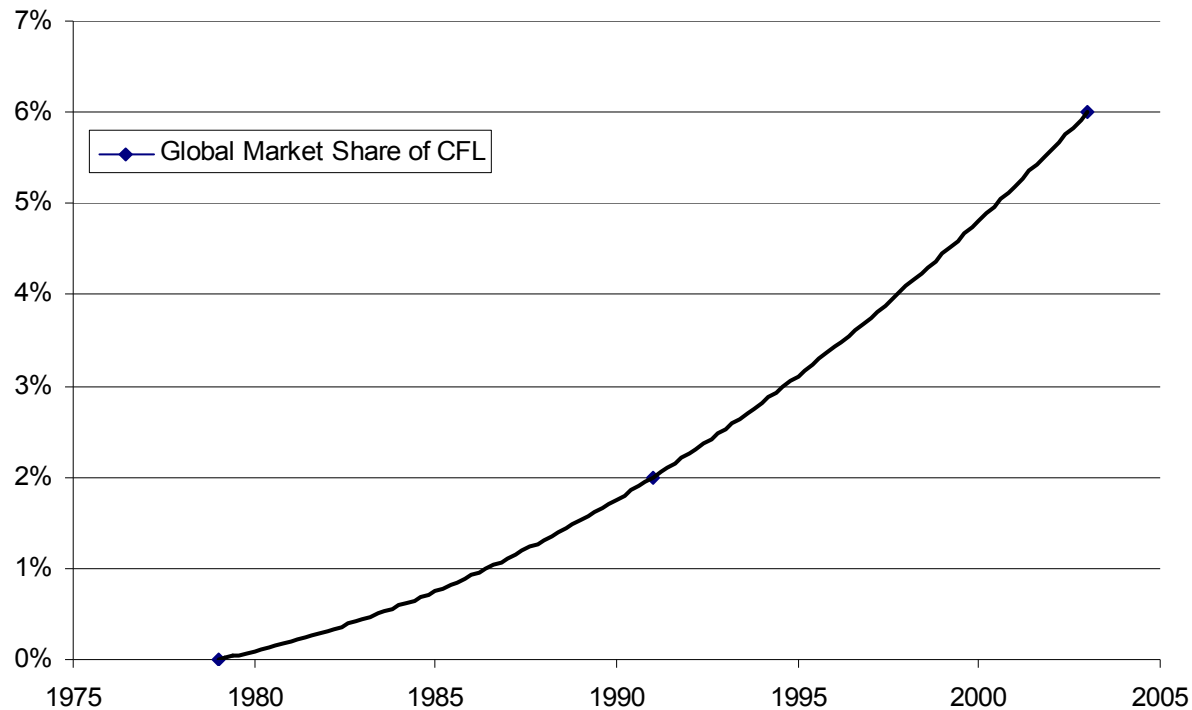
**How long will it take for the
commercialization of SSL?
--Are we there yet?**

Global Light Production by Lamp Type in 2005

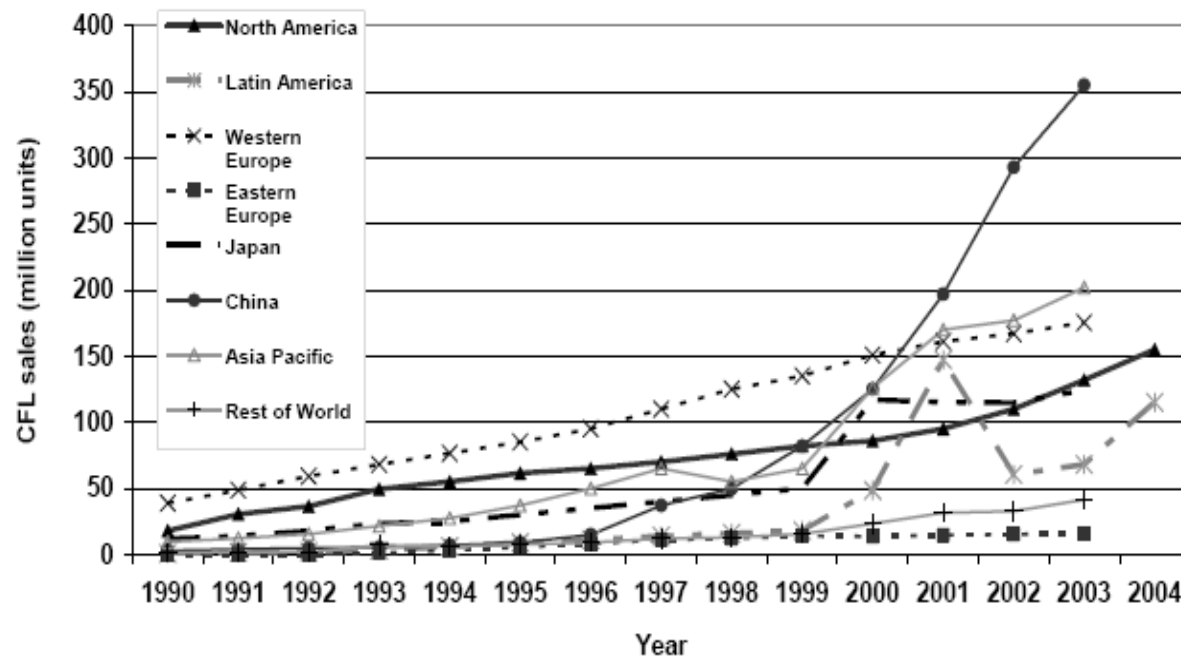


Source: IEA 2006

CFL Adoption

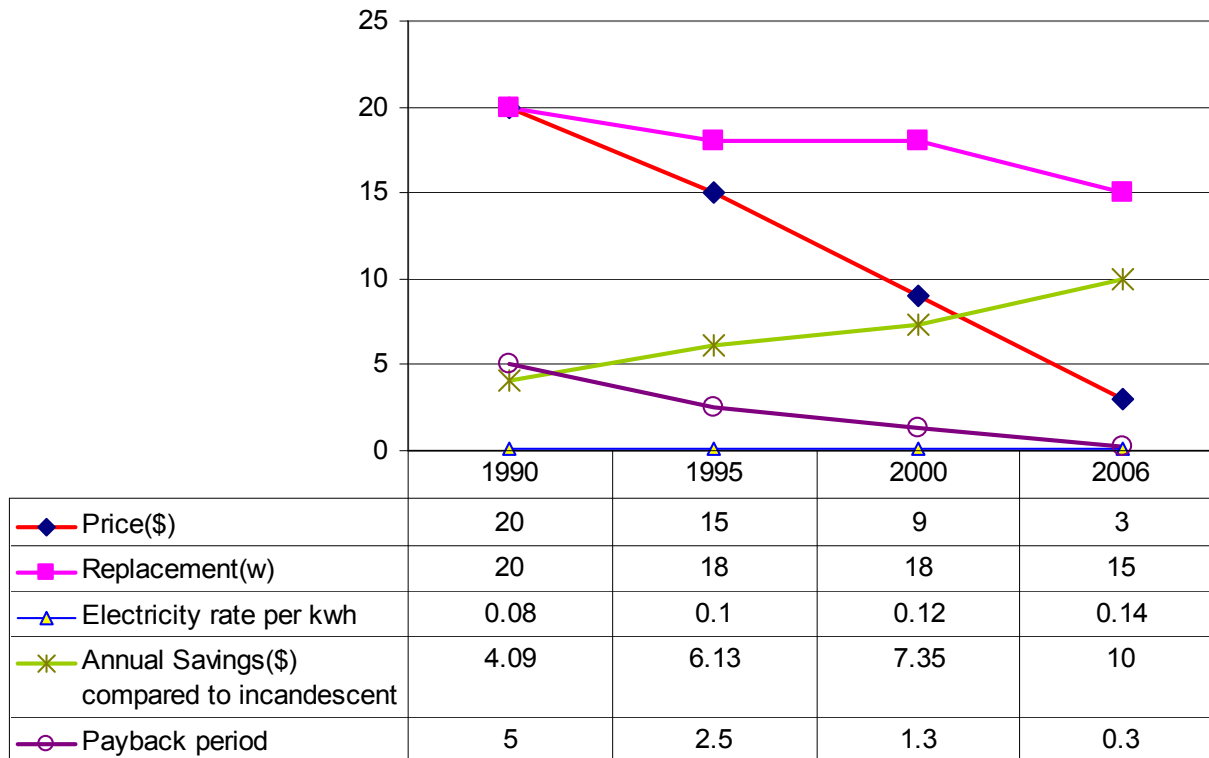


Estimated Global CFL Sales by Region 1990-2004

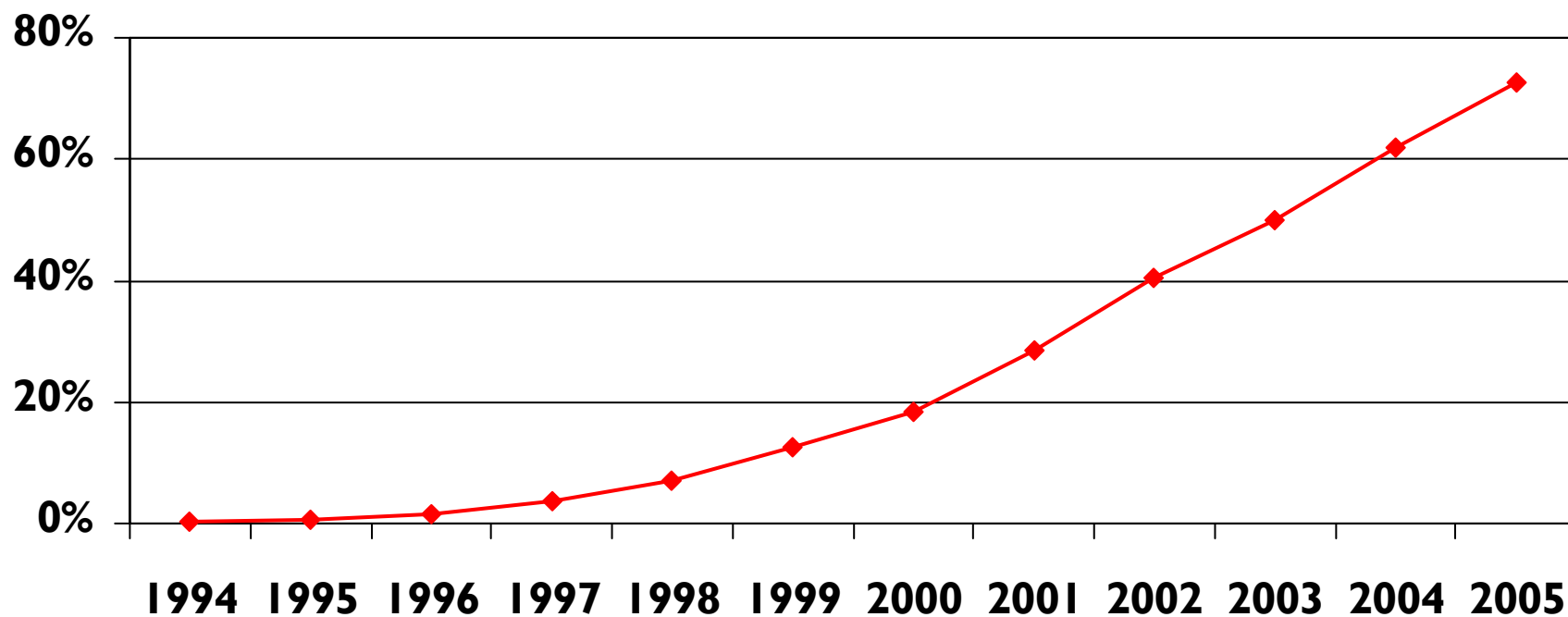


Source: IEA (2006)

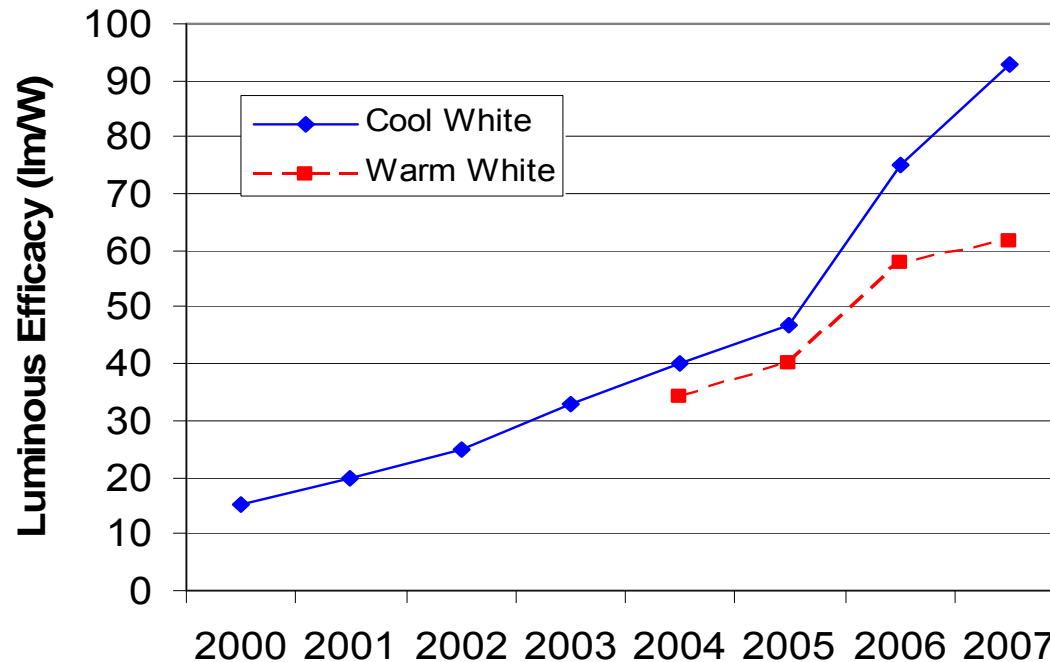
CFLs Performance



North American Red Traffic Signal Market Penetration – Percent of Installed Base



Evolution of White LED Luminous Efficacy (Best Commercial Products)



State-of-the-Art White LED Performance* – Laboratory

- ❑ Small chip (~350 micron square; 20 mA drive current)
 - Nichia – 150 lm/W
 - Cree – 131 lm/W
- ❑ Large chip (\geq 1 mm square; 350 mA drive current)
 - Cree – 129 lm/W
 - Lumileds – 115 lm/W

*Cool white (CCT \geq 4500 K)

State-of-the-Art White LED Performance* – Commercial

- ❑ Small chip
 - Nichia – 96 lm/W
- ❑ Large chip
 - Cree – 93 lm/W
 - Lumileds – 91 lm/W
 - Seoul Semiconductor – 88 lm/W

*Cool white, highest performance bins

Performance of Warm White LEDs

- ❑ Many general illumination applications require a warm white color, similar to that of incandescent lamps
- ❑ Using the appropriate phosphor mix, a variety of warm white (CCT = 2700-3500K) colors can be achieved
- ❑ However, in all cases, the efficacies of warm white LEDs are much less than those of cool white LEDs

Comparison of “Best of Class” Commercial White LED (Large Chip) Luminous Efficacies

Company	Cool White Efficacy (lm/W)	Warm White Efficacy (lm/W)
Cree	93	54
Philips Lumileds	91	54
Seoul Semiconductor	88	55
Nichia	70	61

What is the Competition?



Incandescent R30
\$7
770 lm/75 W
2,000 hrs



CFL R30
\$10
715 lm/16 W
10,000 hrs

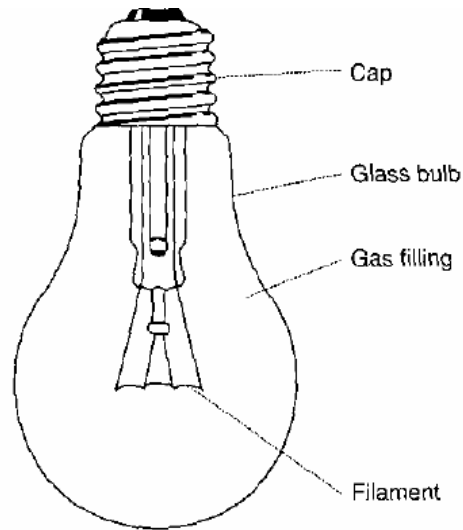


LED R30
\$90
420-500 lm/15 watts
50,000 hrs

Incandescent Lamp

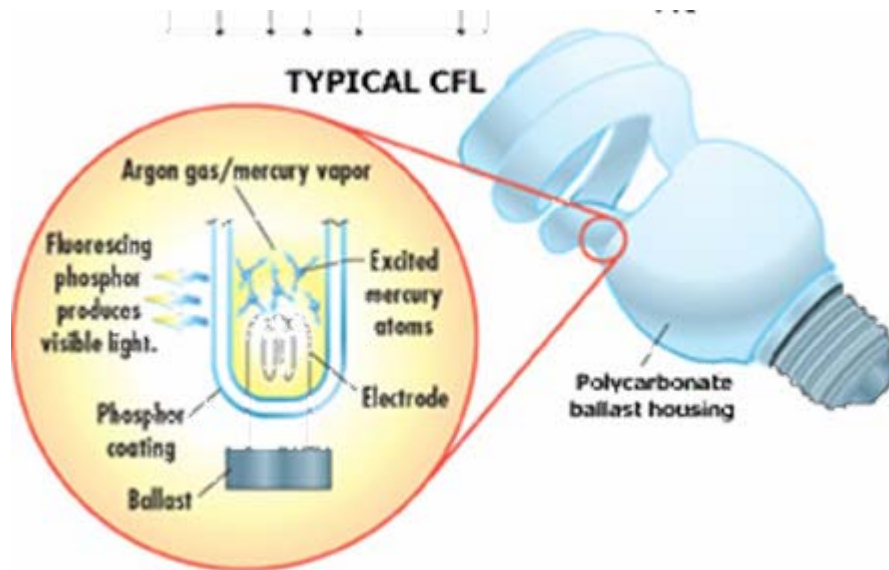


Lamp



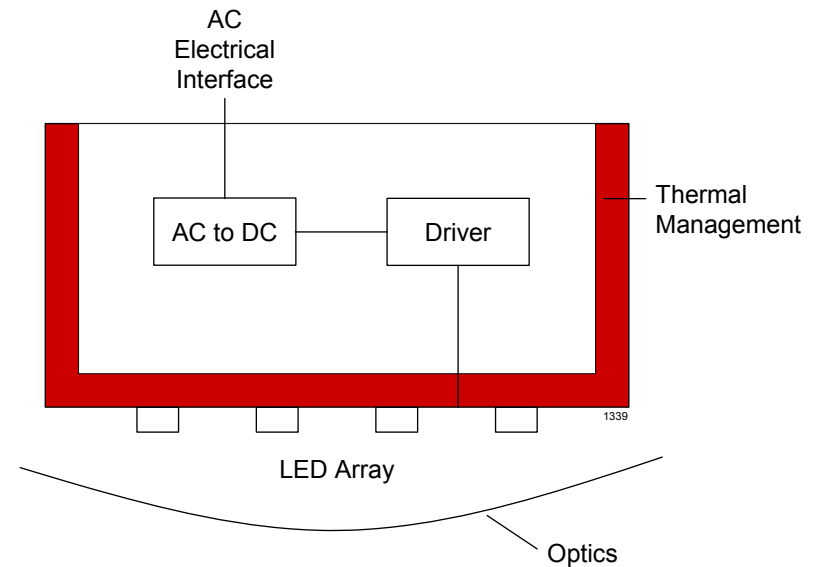
Socket

CFL= Lamp + Ballast



SSL(Lamp Replacements)

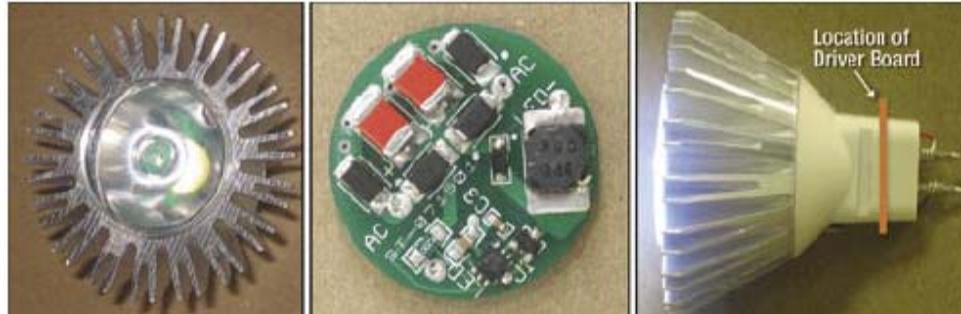
LEDs + Power Supply (driver) +Thermal Management



http://www.wedlake.pwp.blueyonder.co.uk/images/led_lights/inside_reg.JPG

SSL (Lamp Replacements)

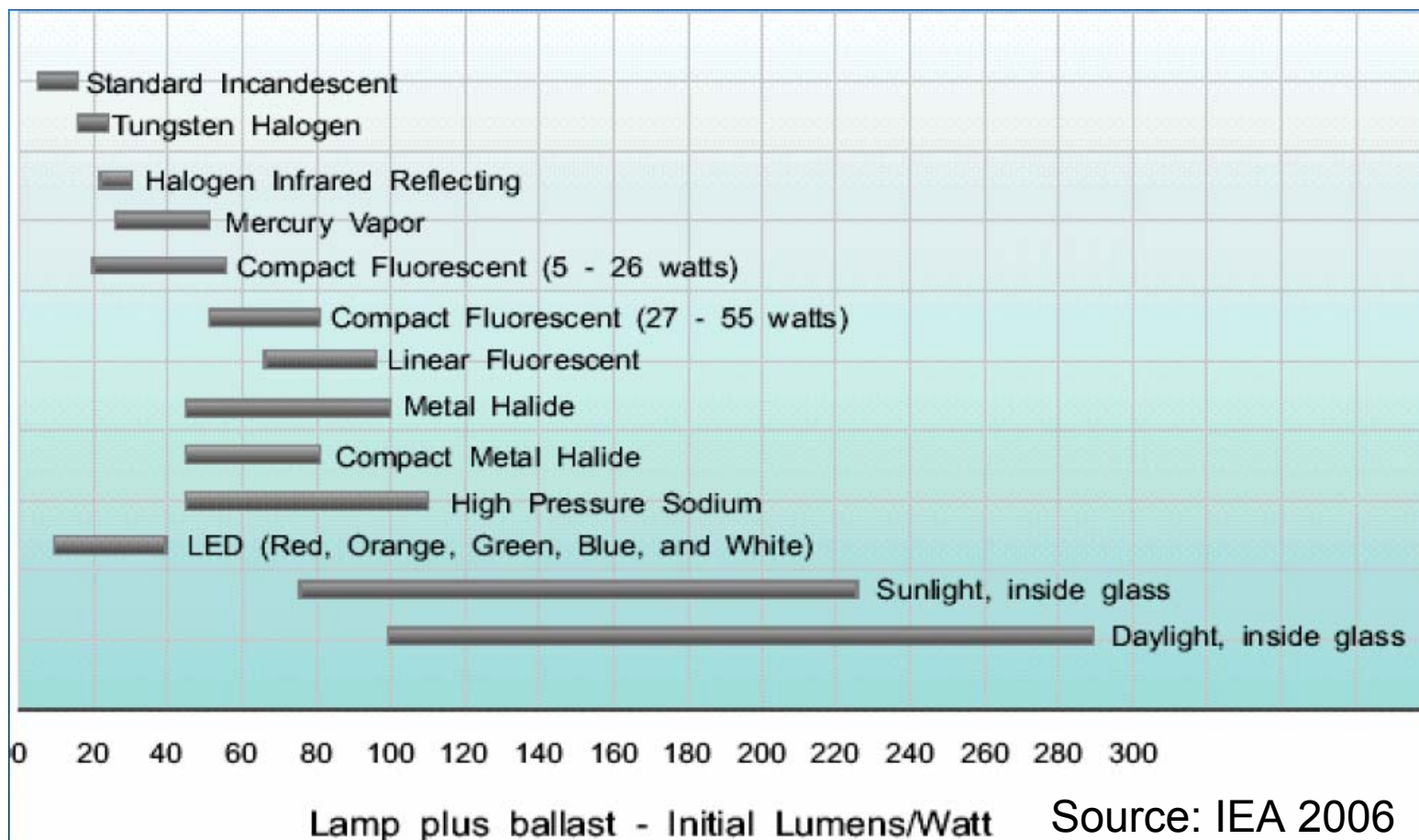
LEDs + Power Supply (driver) + Thermal Management



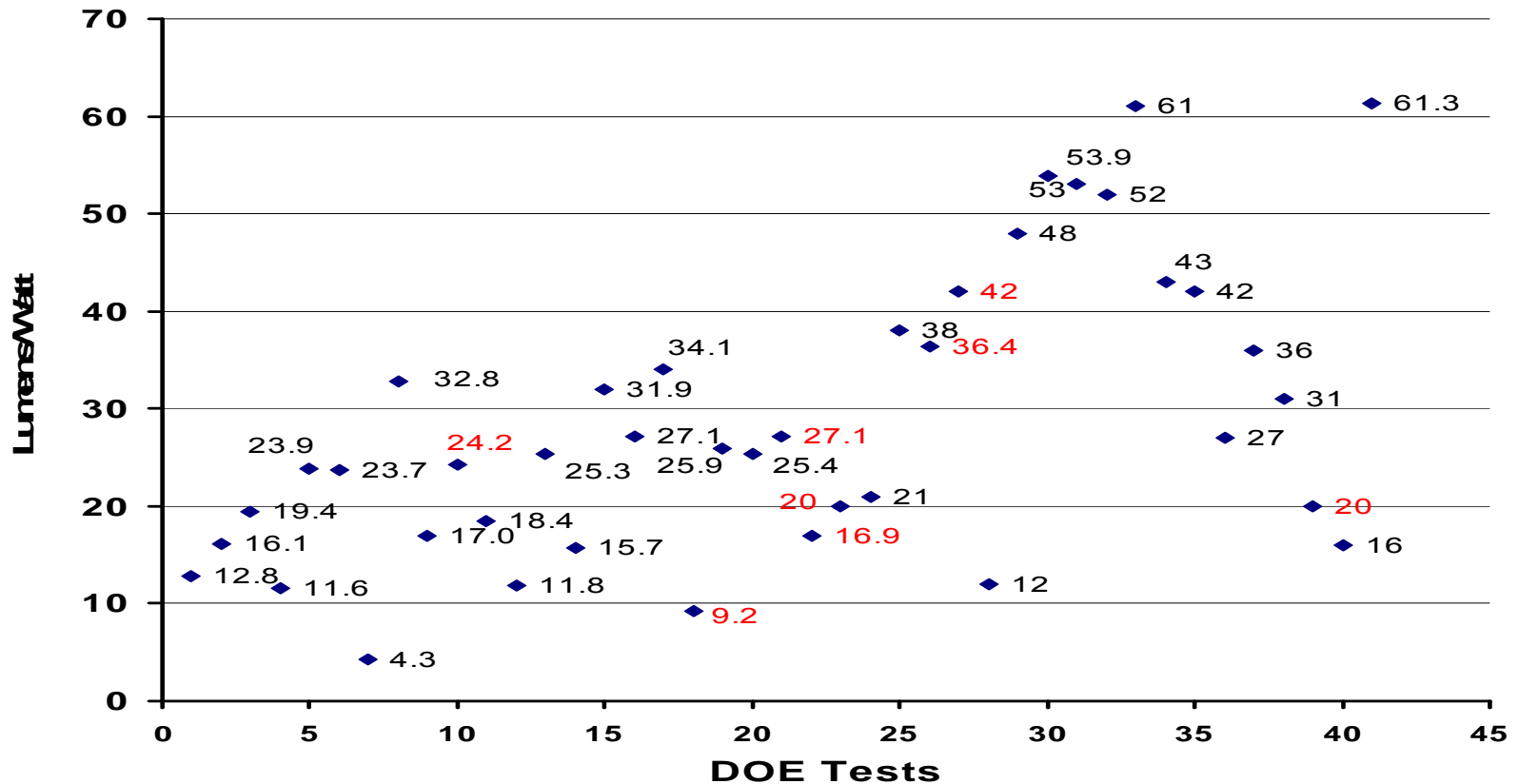
Source: Maxim

Integrated heatsink (left) of the white-LED MR16 lamp and
the compact LED driver circuit (center, Maxim MAX 16820 IC circuit)
which is situated within the lamp housing (right)

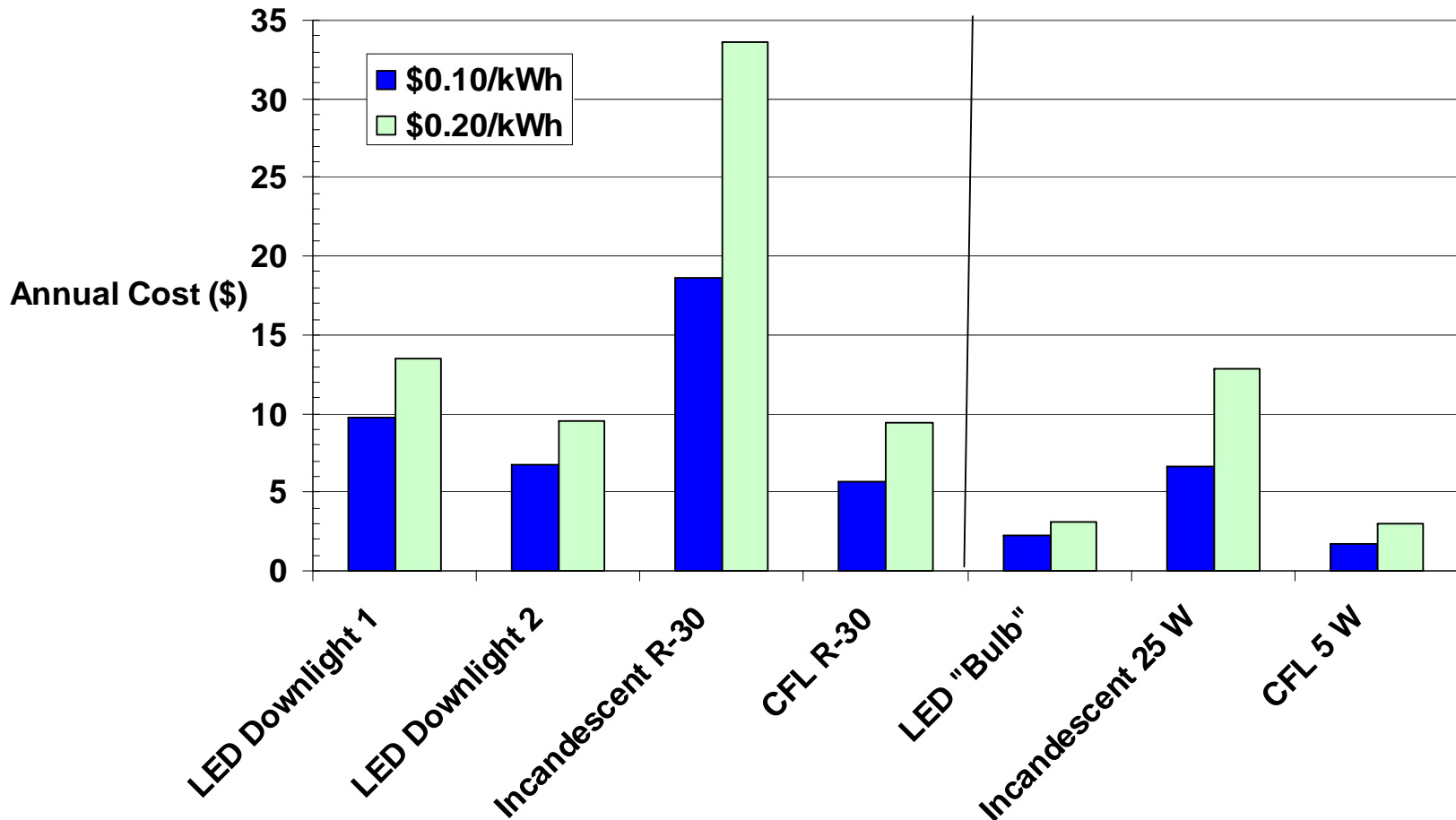
Efficacy Comparison of Light Sources for General Lighting



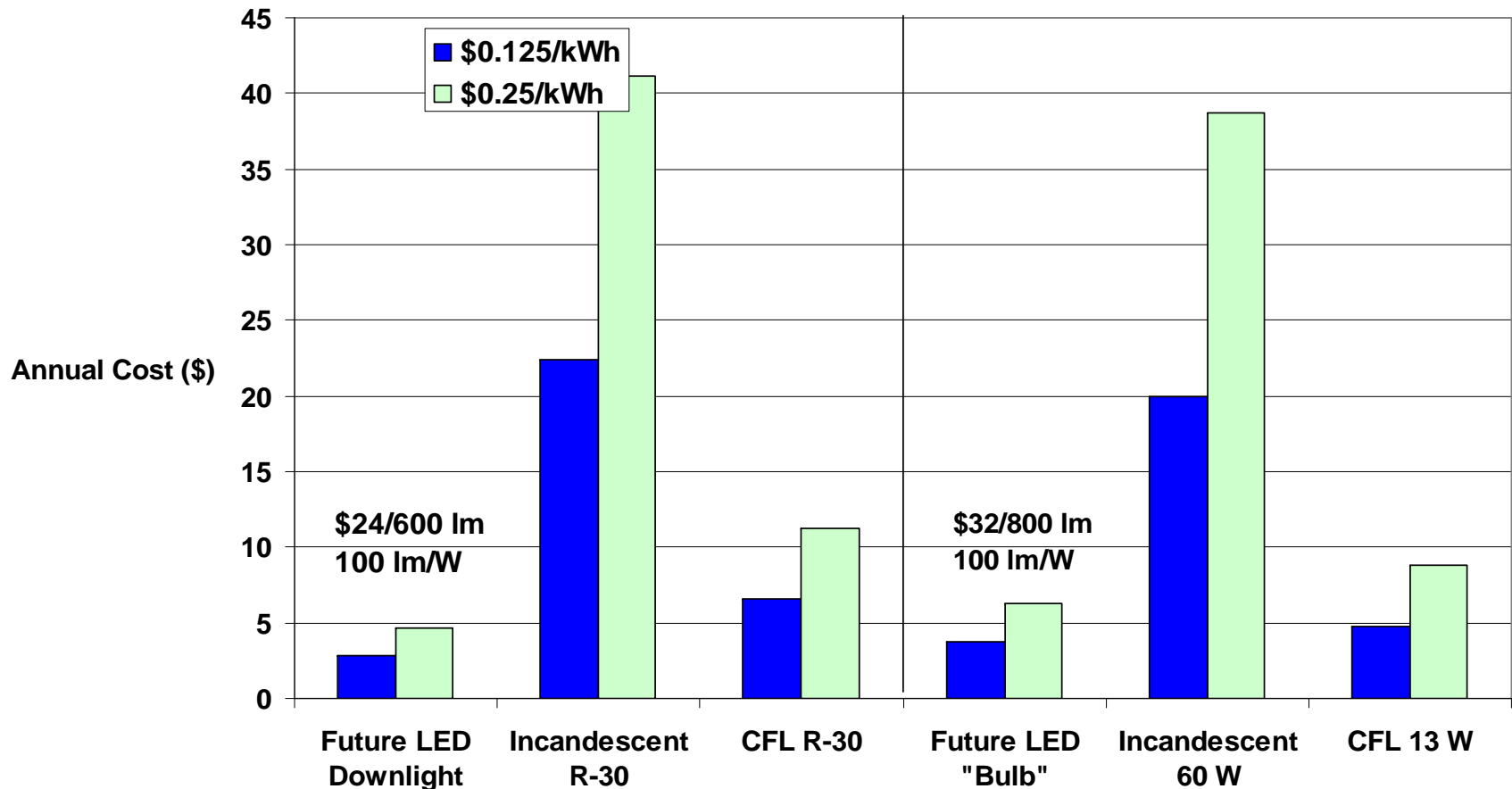
Test Results of Fixtures Tested by DOE



Annual Cost of Lighting (Today)



Annual Cost of Lighting (Future)



Essential Design Principles for LED Light Engines

1. Don't waste electrons
2. Don't waste photons
3. Be cool!

Examples

Efficient Design

Start with 70 lm/W I-W white LEDs (at 25 °C junction temperature)

Assume: 90% electrical efficiency; 90% optical efficiency; operate at 65 °C junction temperature

Light engine efficacy = $70 \times 0.9 \times 0.9 \times 0.85 = \underline{48 \text{ lm/W}}$

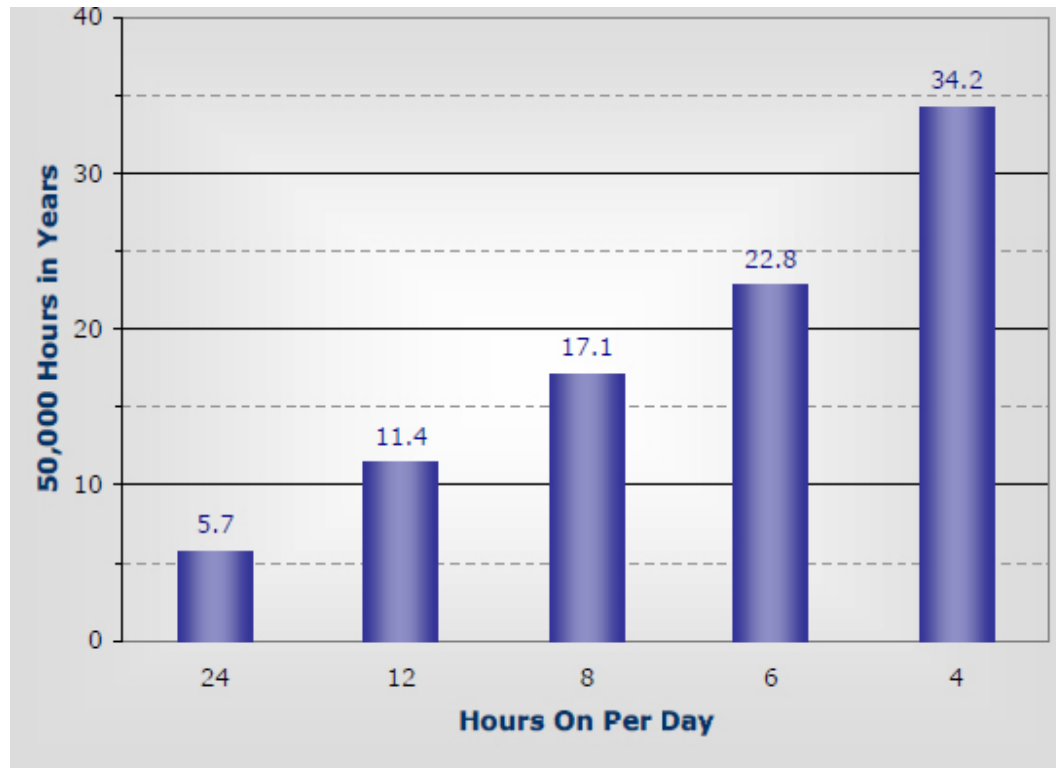
Inefficient Design

Start with 70 lm/W I-W white LEDs (at 25 °C junction temperature)

Assume: 80% electrical efficiency; 80% optical efficiency; operate at 100 °C junction temperature

Light engine efficacy = $70 \times 0.8 \times 0.8 \times 0.75 = \underline{34 \text{ lm/W}}$

What 50,000 Hours Means in Practical Terms



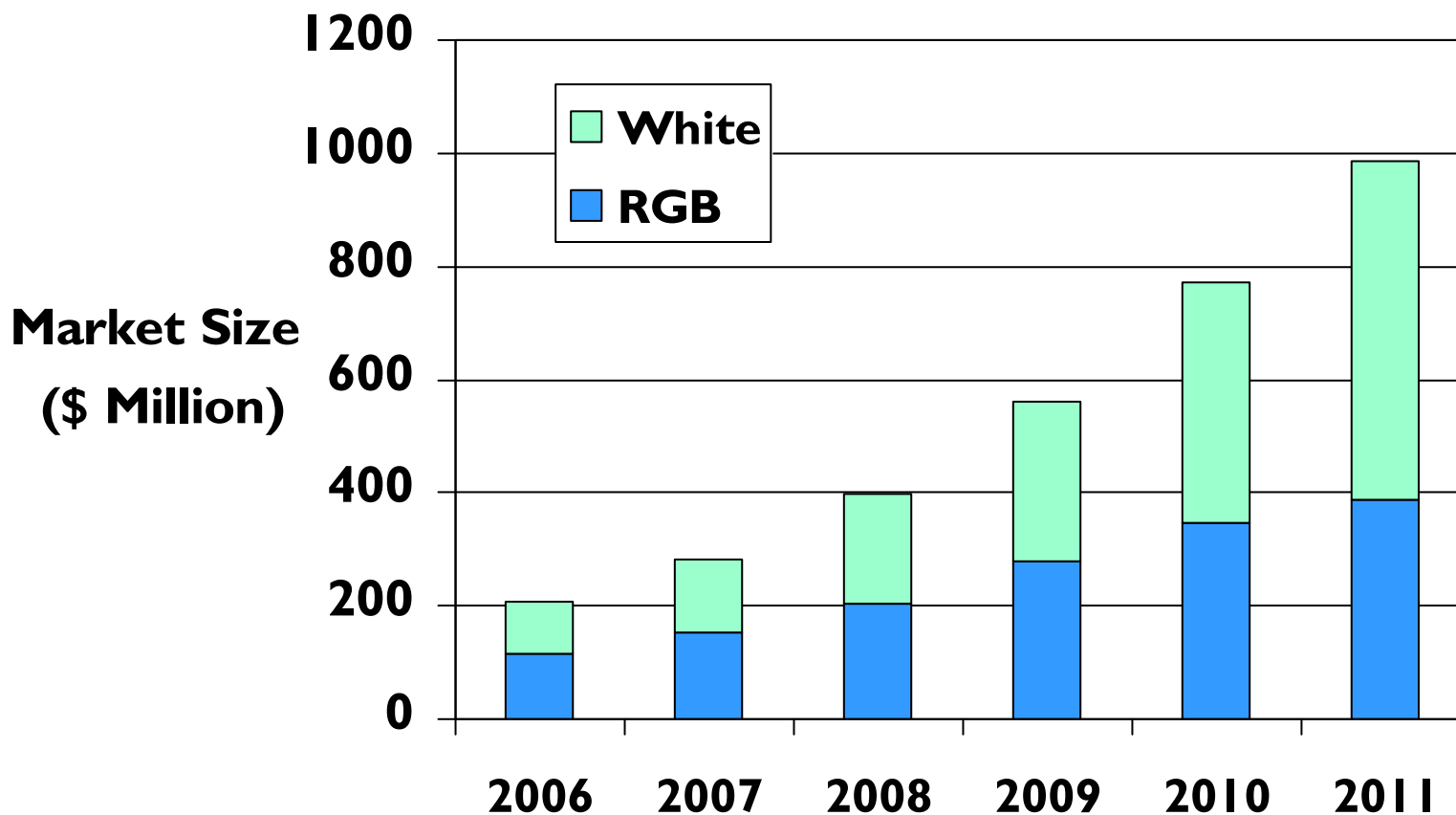
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LED Lighting Market Outlook

- ❑ Niche lighting applications will continue to grow
 - ❑ General illumination (e.g. white light applications) will become increasingly important
 - ❑ Presumes continuing improvement in white LED price/performance
 - And luminaire performance!
 - ❑ Presumes substantial marketing efforts to penetrate the conventional lighting market
 - Penetration will proceed gradually – application by application
 - ❑ Overall forecast 37% CAGR to ~\$1 billion in 2011
-

Forecast for LEDs in Lighting Market



Thank you!